FASERν: Looking forward to neutrinos at the LHC

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Snowmass LOI: [FASERν 2: A Forward Neutrino Experiment at the HL LHC]

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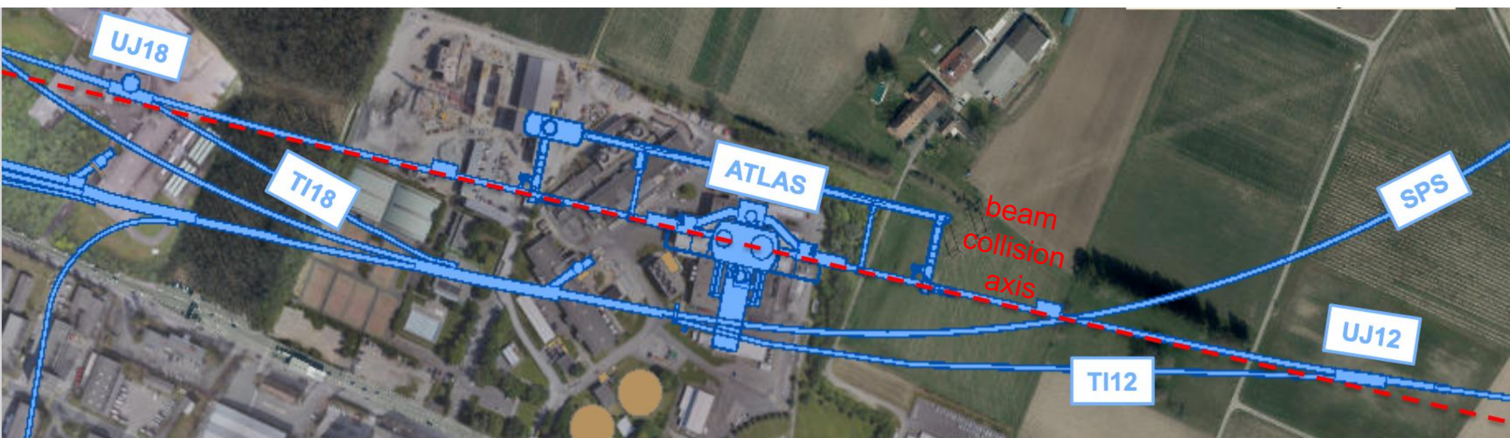
Neutrinos at the LHC

Neutrinos detected from many sources, but not from colliders.

But there is a huge flux of neutrinos in the forward direction, mainly from π, K and D meson decay. De Rujula et al. (1980s)

ATLAS provides an intense and strongly collimated beam of TeV-energy neutrinos along beam collision axis.

The neutrino beam passes through the side tunnels TI12 and TI18, about ~500 m downstream from ATLAS and shielded by ~100 m of rock from the IP, providing a natural location for LHC neutrino experiments.

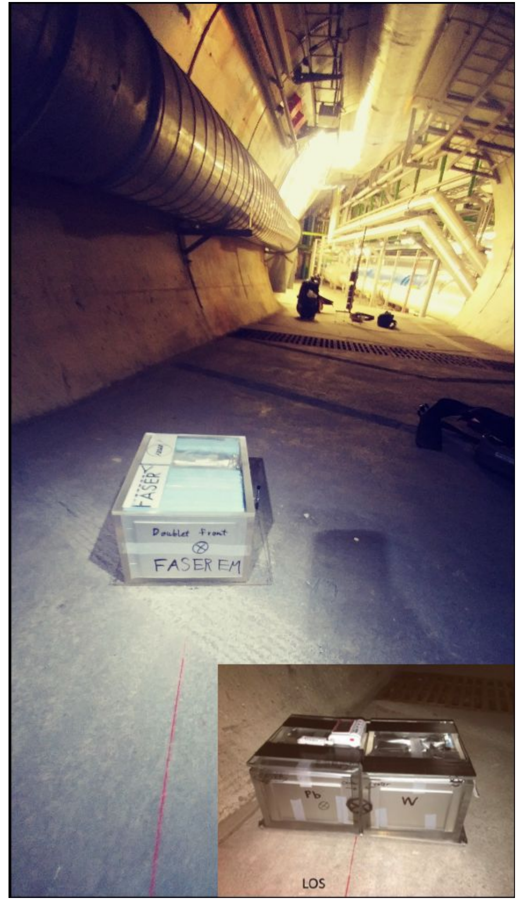


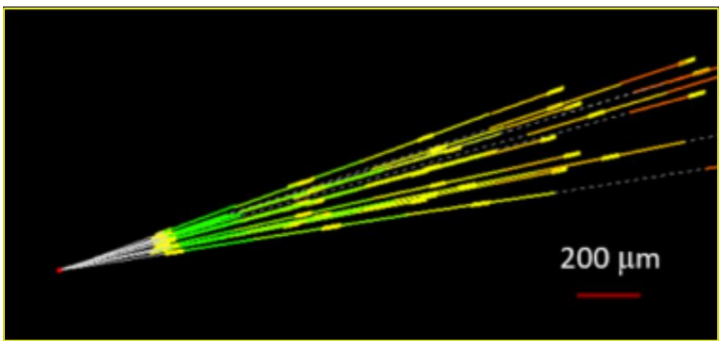
Neutrinos at the LHC

In 2018, the FASER collaboration placed ~30 kg pilot emulsion detectors in the far forward region for a few weeks (inserted and removed in TSs).

Expect ~10 neutrino interactions.

Several neutral vertices have been identified, likely to be neutrinos. Analysis ongoing.

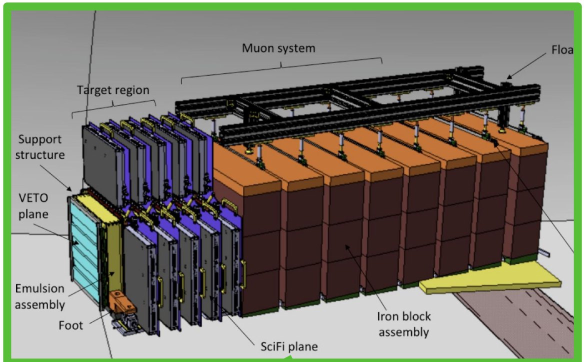




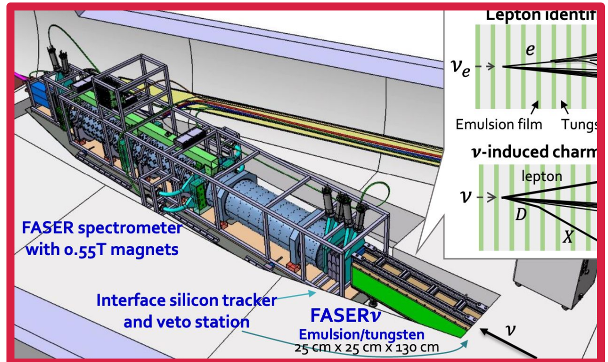
Neutrinos at the LHC

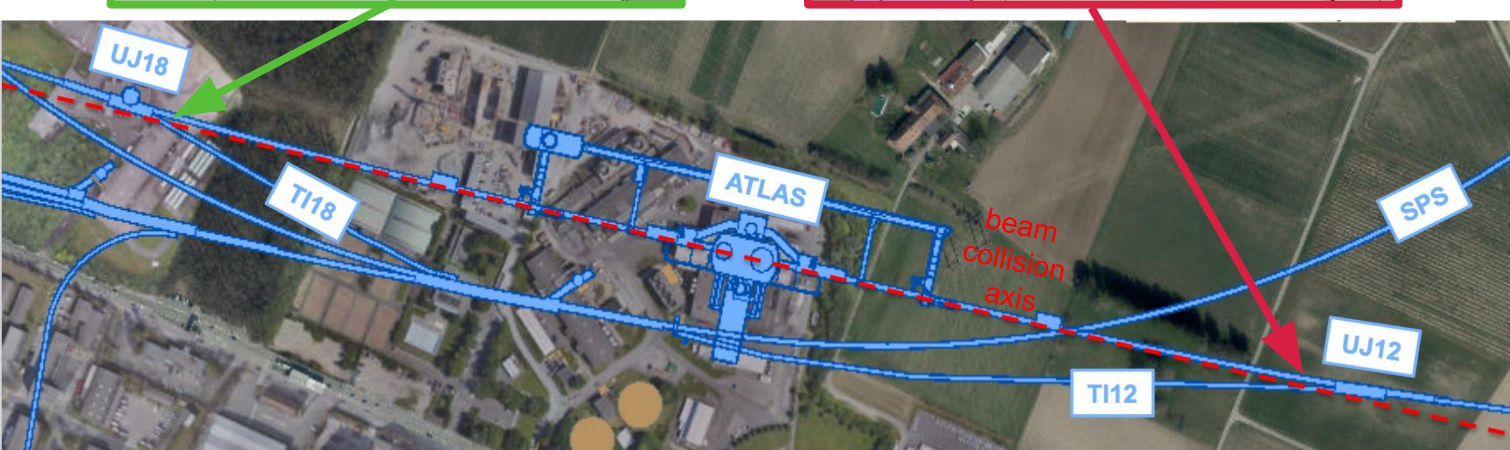
Two collaborations have propose neutrino experiments at the LHC.

SND@LHC (proposed)



FASERnu (approved and funded)

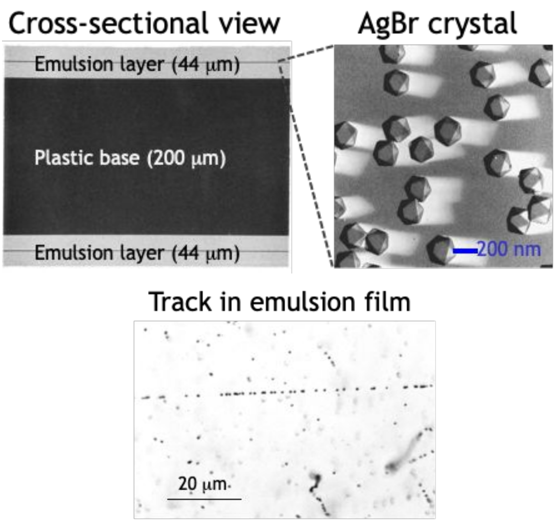


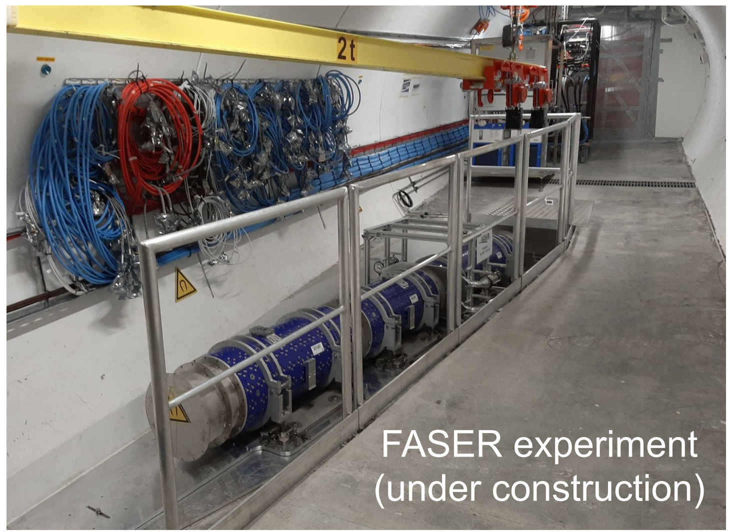


FASERν Neutrino Detector

FASERν is an emulsion neutrino detector, interleaved with tungsten plates as target.
The total target mass is about 1 ton.

The detector is currently under construction. During Run 3 of the LHC (2022-2024), about 1000 electron neutrinos, 10000 muon neutrinos and 10 tau neutrino interactions are expected to be identified.



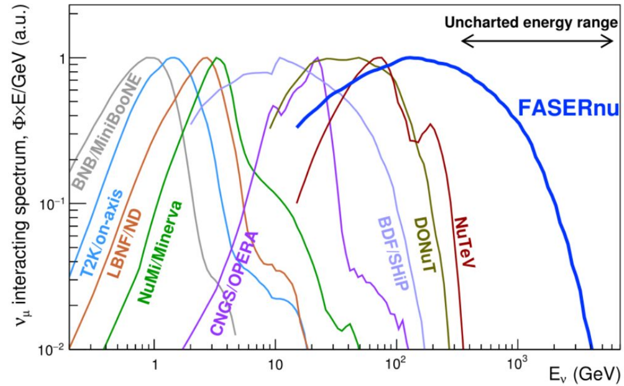


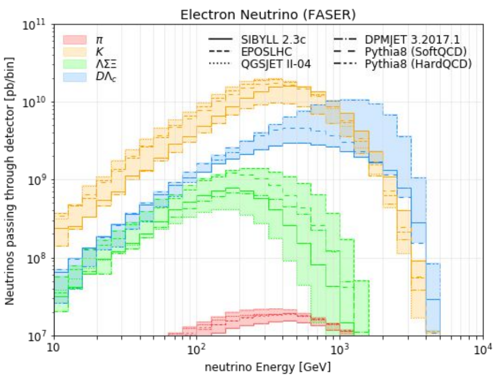
FASERν Neutrino Spectra

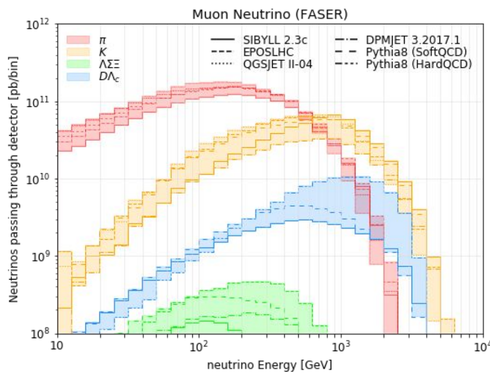
The LHC neutrino beam is broad, with mean energies around 1 TeV, exceeding the energies of all other artificial neutrino sources.

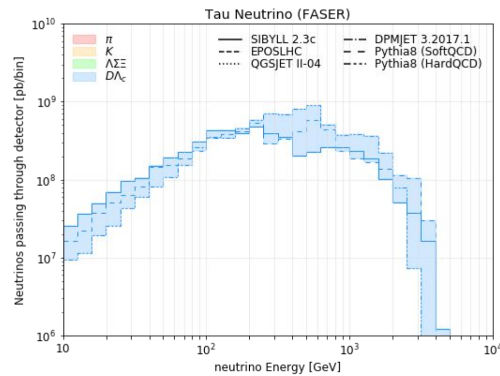
It originates from a variety of sources: pion, kaon, hyperon and charm decays.

It contains all neutrinos and anti-neutrinos of all three flavours.



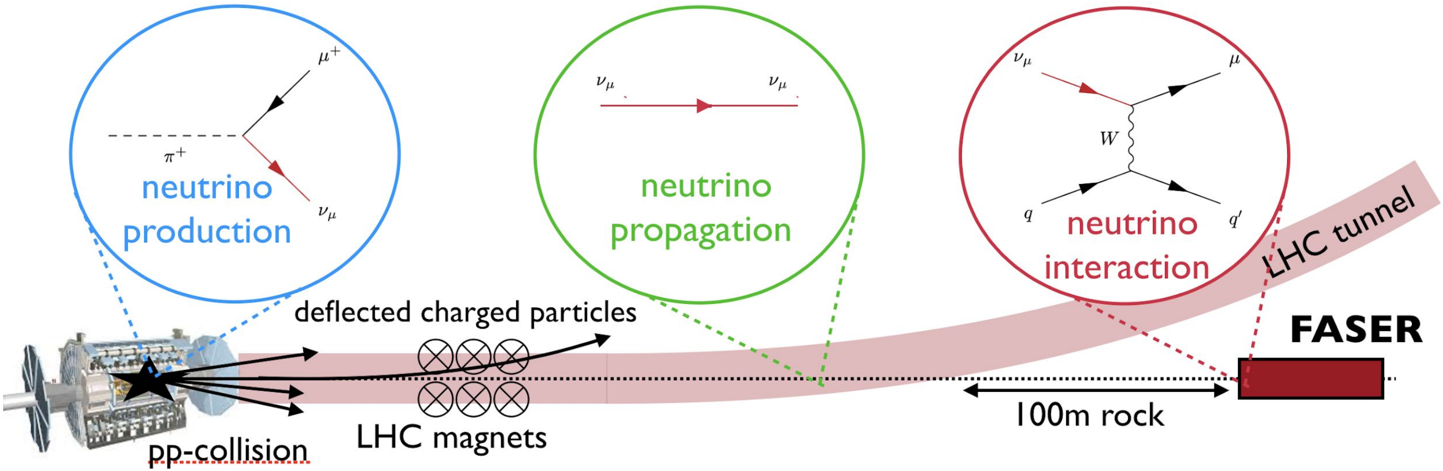






LHC Neutrino Physics Potential

What can we do learn from those neutrinos?

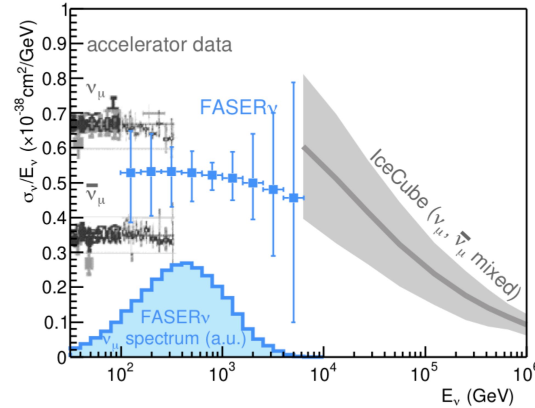


In the following, I will present some ideas.

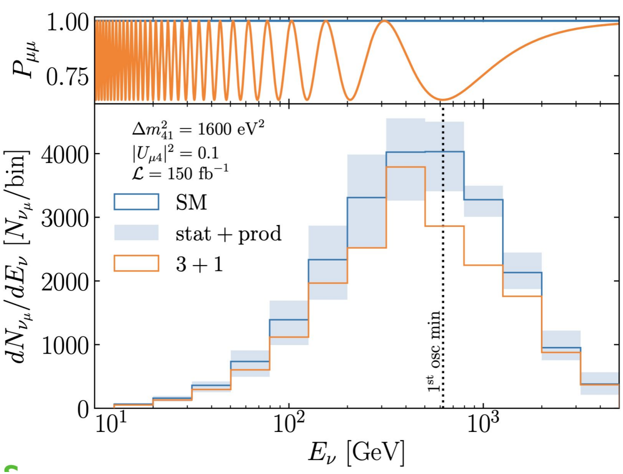
Most of them were not investigated in detail yet.

Neutrino Physics

FASERν will measure neutrino cross section at unexplored TeV energies for all three flavors. Both CC and NC are possible.



FASERν will detect ~10 tau neutrino interactions, which is similar to DONuT and OPERA. Thousands of tau neutrino events possible at HL-LHC, allowing for precision studies of tau neutrino properties.

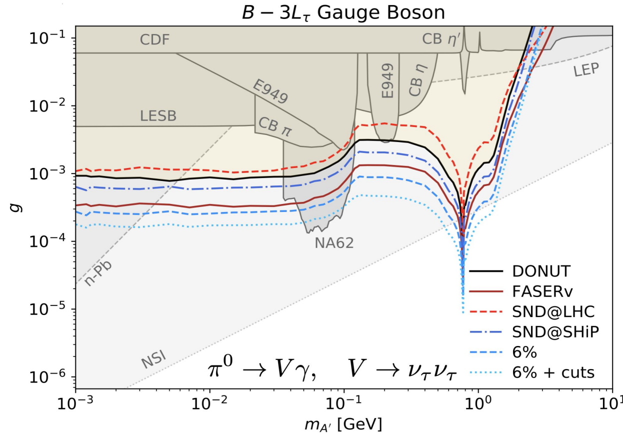


FASERν will record neutrino interaction event shapes with high precision. This could be useful for validation/tuning of neutrino event generators.

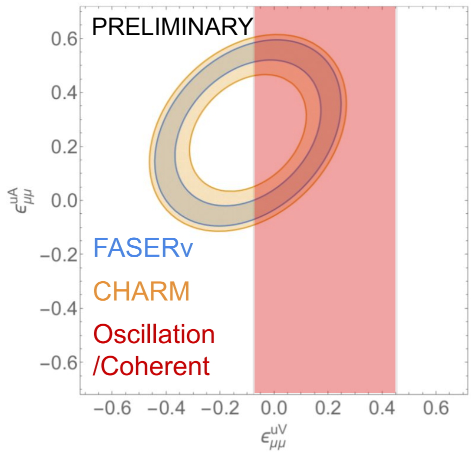
SM neutrino oscillations are expected to be negligible at FASERν. However, sterile neutrinos with mass ~40eV can cause oscillations. FASERν could act as a short-baseline neutrino experiment.

BSM Physics

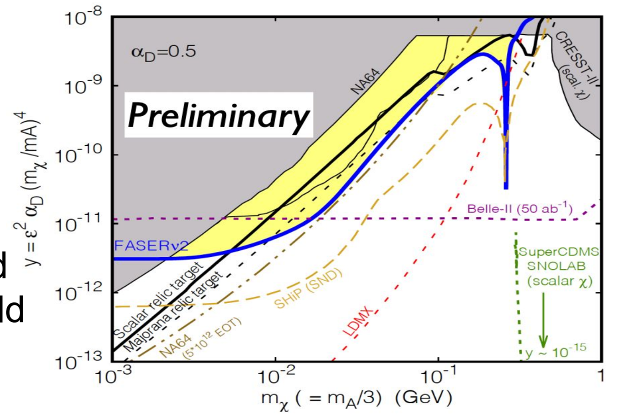
The tau neutrino flux small in SM. A new light weakly coupled gauge bosons decaying into tau neutrinos could significantly enhance the tau neutrino flux. Kling 2005.03594



NC measurements at FASERv could constrain neutrino non-standard interactions (NSI). Abraham, Ismail, Kling 2020 (to appear)

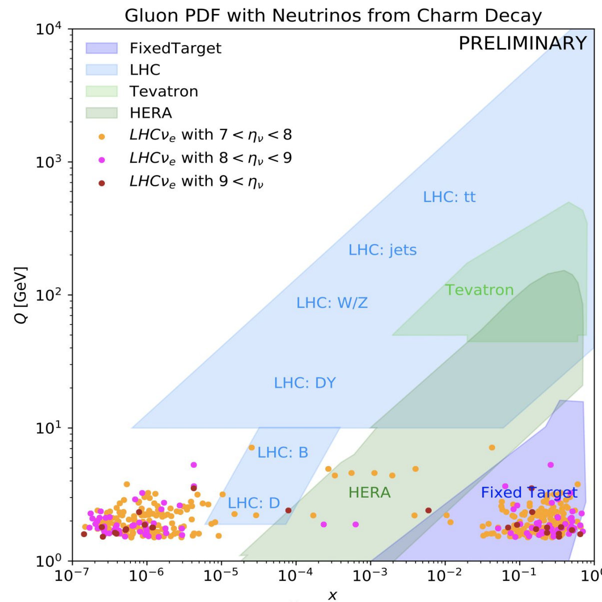


If DM is light, the LHC can produce an energetic and collimated DM beam towards FASERv. FASERv could therefore also search for DM scattering. Batell, Feng, Trojanowski 2020 (to appear)

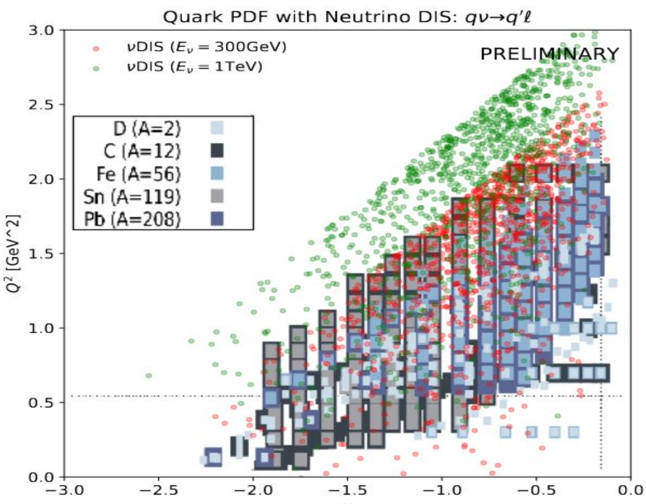


QCD

Forward particle production is poorly constrained by other LHC experiments. FASERν's neutrinos flux measurements will provide novel complimentary constraints that can be used to validate/improve MC generators.



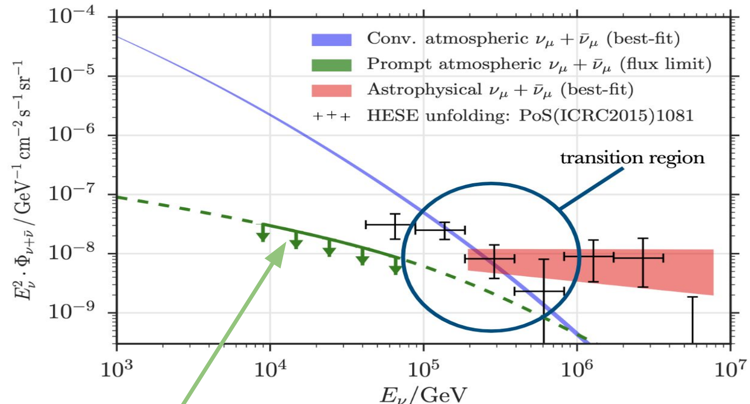
Neutrinos from charm decay could allow to test transition to small-x factorization, constrain low-x gluon PDF and probe intrinsic charm.



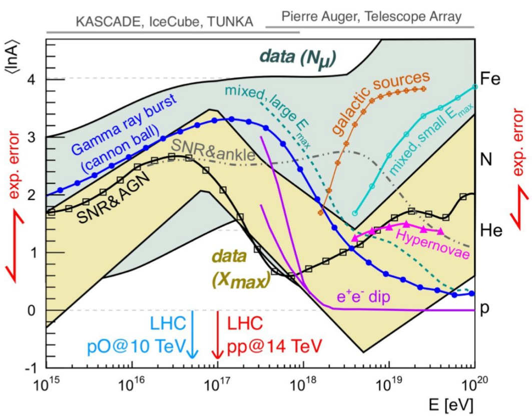
It might also be possible to probe (nuclear) PDFs via DIS neutrino scattering. In particular, charm associated neutrino events ($\nu\ s \to l\ c$) are sensitive to the poorly constrained strange quark PDF.

Cosmic Rays and Neutrinos

In order for IceCube to make precise measurements of the cosmic neutrino flux, we need accelerator measurements of high energy and large rapidity charm production.



prompt atmospheric neutrinos



Based on Kampert & Unger, Astropart. Phys. 35 (2012) 660

Muon problem in CR physics: Cosmic Ray experiments have reported an excess in the number of muons over expectations computed using extrapolations of hadronic interaction models tuned to LHC data at the few σ level.

New input from LHC is crucial to reproduce CR data consistently.

Summary

FASERν is approved, funded and under construction. It will soon measure the first neutrinos at the LHC.

FASERν also paves the way for a high-energy forward neutrino physics program at the HL-LHC, opening up many many new opportunities for neutrino physics, new physics searches and QCD measurements, significantly extending the LHC's physics program.

For Snowmass 2021, we propose a detector with roughly ten times the mass of FASERν operating at the HL-LHC. Such a detector would collect roughly 100k electron neutrinos, ~1M muon neutrinos and ~1k tau neutrinos at TeV energies.

We would like to invite the NF09 community to help us better understand the LHC as neutrino source and explore the physics potential of this program.